

# **SANDIA REPORT**

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**Hydrogen Fueling Infrastructure Research and Station Technology**

**A partnership to advance hydrogen fueling station technology,  
driving an optimal consumer experience**

**Sandia National Laboratories, Livermore, California**

Christopher Moen, Daniel Dedrick, Aaron Harris, Joseph Pratt, Bruce Balfour, Christopher San Marchi, Brian Somerday and Edwin Noma

**National Renewable Energy Laboratory, Golden, Colorado**

Jennifer Kurtz, Keith Wipke, Samuel Sprik, Kevin Harrison and Danny Terlip

Prepared by  
Sandia National Laboratories  
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Jennifer Kurtz  
Keith Wipke  
Samuel Sprik  
Kevin Harrison  
Danny Terlip

Sandia National Laboratories  
P.O. Box 969  
Livermore, CA 94550

### **Abstract**

The US Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) Office of Fuel Cell Technologies Office (FCTO) is establishing the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) partnership, led by the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL). FCTO is establishing this partnership and the associated capabilities in support of H2USA, the public/private partnership launched in 2013. The H2FIRST partnership provides the research and technology acceleration support to enable the widespread deployment of hydrogen infrastructure for the robust fueling of light-duty fuel cell electric vehicles (FCEV). H2FIRST will focus on improving private-sector economics, safety, availability and reliability, and consumer confidence for hydrogen fueling. This whitepaper outlines the goals, scope, activities associated with the H2FIRST partnership.

## ACKNOWLEDGMENTS

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## **NOMENCLATURE**

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## 1. Overview

The US Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) Fuel Cell Technologies Office (FCTO) is establishing the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) partnership, led by the National Renewable Energy Laboratory (NREL)<sup>1</sup> and Sandia National Laboratories (SNL)<sup>2</sup>. FCTO is establishing this partnership and the associated capabilities in support of H2USA<sup>3</sup>, the public/private partnership launched in 2013. The H2FIRST partnership provides the research and technology acceleration support to enable the widespread deployment of hydrogen infrastructure for the robust fueling of light-duty fuel cell electric vehicles (FCEV). H2FIRST will focus on improving private-sector economics, safety, availability and reliability, and consumer confidence for hydrogen fueling. NREL and SNL will co-lead the H2FIRST partnership to solve technical challenges for both critical-path fueling station deployment in the near term and long-term optimization of stations and station networks. Industry participation is needed to achieve relevancy. The impact of H2FIRST is enhanced by coordination with State governments and agencies, for example, the California Governor's Office of Business Development (GO-Biz), the California Energy Commission (CEC), California Air Resources Board (ARB) and the Air Quality Management Districts (South coast AQMD and Bay Area AQMD).

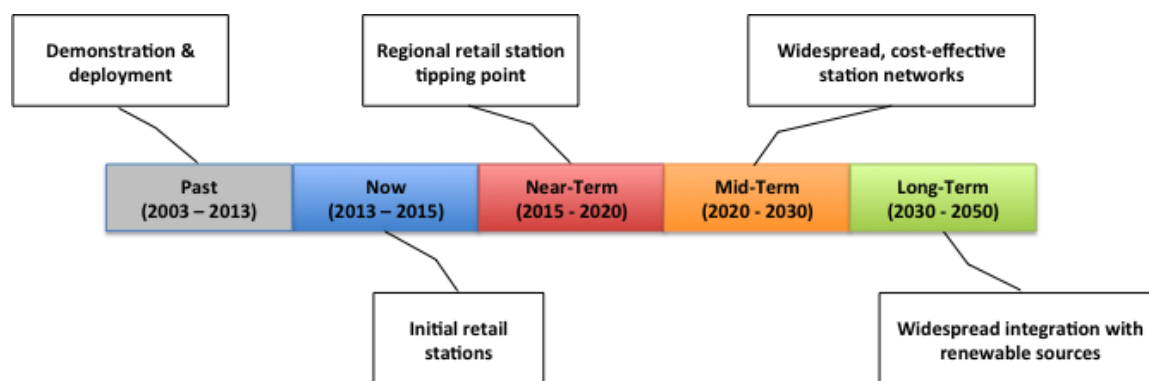


Figure 1: H2FIRST includes work that spans from urgent and immediate needs to reach an economic tipping point to the longer term of full-scale deployment (out to 2050) in a broader energy eco-system.

The California Energy Commission's *Hydrogen Fuel Infrastructure* solicitation and the California Fuel Cell Partnership's *Commercialization Roadmap* cite the need for hydrogen fueling to closely mimic gasoline fueling -- retail customers will expect high-performing hydrogen stations which mirror their gasoline counterparts with no compromises with respect to availability, throughput, and ease of use.

H2FIRST's mission is to ensure that FCEV customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are introduced (2015-2017) and transition to

<sup>1</sup>NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

<sup>2</sup>Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

<sup>3</sup> H2USA mission: To promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private partnership to overcome the hurdle of establishing hydrogen infrastructure.

advanced refueling technology beyond 2017. The most urgent need is to support the fueling experience for the vehicle roll-out occurring now (see Figure 1). The near term need (2015-2020) is to achieve a tipping point in fueling infrastructure deployment in regions like California. Mid-term needs (2020-2030) and long-term needs (2030-2050) to scale up the fueling infrastructure are driven by State and Federal goals to reduce oil consumption and reduce greenhouse gas emissions.

Open and available fueling stations, with competitively priced hydrogen, will enable consumer adoption of FCEVs. H2FIRST's high-level technical goals are focused on reducing the cost and time of fueling station construction along with improving the stations' availability and reliability, while maintaining fueling times on par with liquid fuels. H2FIRST will develop and apply physical testing, numerical simulation, and technology validation capabilities to support U.S. industry innovation for new, low-cost, high-performance materials, component technologies, and station architectures. H2FIRST will also collect and distribute data supporting industry's efforts to reduce the costs of integrated fueling systems and networks. Specific objectives are:

**Station Optimization and Innovation** – Reduce the installation cost of a hydrogen fueling station to be competitive with conventional liquid fuel stations. Enable greater innovation of fueling station and station network designs that will meet the needs and opportunities of the consumer market. Develop reference station designs to provide greater fidelity in our understanding of the barriers inhibiting the realization of a hydrogen fueling infrastructure. Provide quantitative station and station network requirements, cost targets, and performance/reliability metrics.

**Cost, Reliability, and Performance Engineering** – Reduce the combined cost of compression, storage, and dispensing (CSD) to the DOE 2020 goal of \$0.70/gge. Improve the availability and reliability while ensuring the safety of high-pressure components in an integrated system through material solutions and novel designs.

**Deployment Acceleration** – Focus a flexible and responsive set of technical experts and facilities to help solve today's urgent challenges and the unpredicted needs that will come up for hydrogen stations.

**Renewable Hydrogen and Grid Integration** – Develop, optimize, and validate technologies that enable distributed generation of renewable hydrogen in a broader energy ecosystem.

In order to capitalize on the hydrogen station and vehicle momentum evidenced by the launch of H2USA, automotive OEM partnerships, and vehicle production schedules, H2FIRST will take the following actions:

- perform objective research, development, and demonstration focused on overcoming technical barriers in hydrogen fueling of FCEVs, based on the anticipated critical needs for near-term hydrogen station deployment,
- provide enabling laboratory capabilities that can serve many purposes for advancing hydrogen fueling technologies and accelerating the introduction of disruptive technologies into the marketplace, and
- ensure continued relevance of activities through appropriate industry engagement, teaming with industry, academia, laboratories, and government.



H2FIRST’s brass-board test facilities (SNL’s Center for Infrastructure Research and Integration and NREL’s Energy Systems Integration Facility and Distributed Energy Research Testing Facility, see Figure 2) will serve many purposes for advancing technology. They will be able to generate the data required to characterize and validate forecourt concepts and systems that are deemed urgent, too uncertain, or financially risky to attempt at commercial stations. The brass-board facilities will perform accelerated testing of the forecourt systems to identify needs and feed results back into the development process.



Figure 2: SNL and NREL are coordinating capabilities to address technical challenges, providing physical venues for technical collaborations among diverse stakeholders.

## 2. Approach & Capabilities

H2FIRST is a collaboration of partners, capabilities, and experts focused on accelerating hydrogen fueling innovation, defined as improvements to the cost, safety, availability, and performance of high pressure hydrogen systems. A systems approach to the entire fuel dispensing process is required to optimize and co-evolve both the vehicle storage tank and the dispensing system (see Figure 3). The fueling system is defined as the fueling station hardware and includes the vehicle pressure boundary during fueling. While H2FIRST is not concerned with furthering hydrogen production or delivery technology, our scope does include optimizing the use of on-site or distributed renewable production in a fueling network.

Collaboration between NREL and SNL to improve the reliability and performance of commercial fuel station components is a natural intersection of available resources. Combining SNL’s expertise in hydrogen science, materials research, and systems engineering with NREL’s expertise in integration, testing, and analysis of component-to-system hardware enables H2FIRST to produce high-impact research results with strong industry, academic, and government collaborations in a fiscally responsible manner. An additional collaboration with Argonne National Laboratory (ANL) will provide critical validation data for system models like H2A and HDSAM.

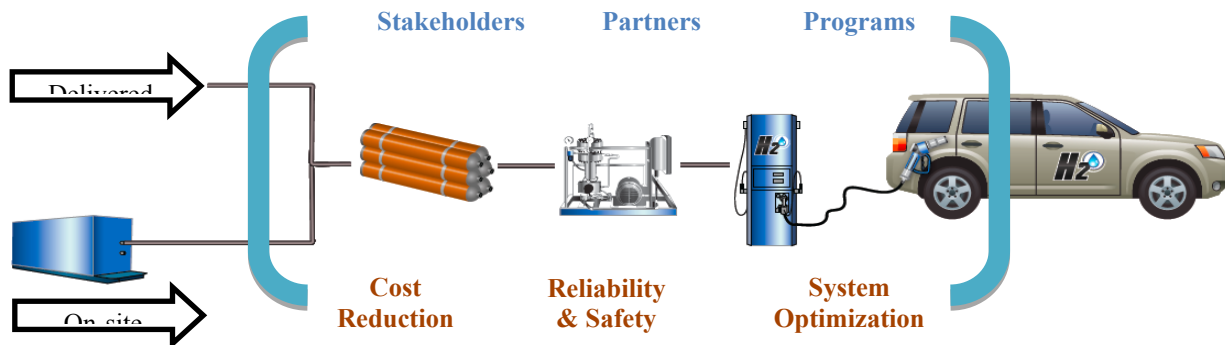


Figure 3: The research, development, and demonstration scope includes the fueling station and the interaction with a vehicle during fueling. Distributed and on-site hydrogen production is included to the extent of optimizing the design of a fueling station or station network.

The research elements of H2FIRST include the following:

**Systems:** develop and demonstrate optimal fuel stations and station network architectures and approaches to delivery and dispensing that meet customer expectations and infrastructure cost targets; provide validation points for existing techno-economic models.

**Components:** establish credible component reliability, component cost, and operating cost targets for hydrogen fueling stations and develop a roadmap from current baseline to targets; improve the performance and/or reliability of critical fueling station components such as tanks, compressors, hoses, meters, and valves while maintaining safety; develop and validate intelligent fuel dispensing approaches.

**Materials:** develop and characterize low-cost, high-performance materials for extreme temperature and pressure conditions used in the various parts of hydrogen fueling; solve component reliability problems by understanding structural performance and providing material solutions.

**Grid integration and carbon reduction:** develop and demonstrate technologies that enable distributed generation of renewable hydrogen in a broader energy eco-system.

H2FIRST will evaluate new materials, emerging component technology and novel system architectures in reconfigurable hydrogen delivery and dispensing test loops. Performance and reliability issues will be addressed using a science-based approach with the intent of predicting aging behavior and lifecycle costs, utilizing a national network of tools, research capabilities, and testing. These include information databases, high-pressure materials/component/system testing and validation facilities, and systems integration demonstration facilities (*e.g.* ESIF, DERTF, and CIRI). An incubation and innovation program is included to support the introduction of disruptive infrastructure technologies into the marketplace. H2FIRST will consider the placement of Industrial Fellows to increase interaction between the private sector and the National Laboratories at the senior technical level around fueling infrastructure.

Our strategic approach utilizes complimentary capabilities (facilities and personnel expertise) and takes advantage of the strengths of each Laboratory, and also provides some parallel testing overlaps for capacity. Specific facilities are:

**Energy Systems Integration Facility (ESIF)** – high pressure component test bays, hydrogen production, full scale system/component test station, safety sensor lab, energy system integration lab, seasonal and temperature variations, National Fuel Cell Technology Evaluation Center (NFCTEC);

**Distributed Energy Resources Test Facility (DERTF)** – reliability test loop, renewable production, direct coupling power management;

**Center for Infrastructure Research and Integration (CIRI)/Full Scale Hydrogen Research Facility (HyReF)** – full scale system/components test loop, over-pressure evaluation, under/over temperature conditions, dispensing protocols, location proximity to Sacramento and customer vehicles in California;

**CIRI/Hydrogen Metallurgy Lab** – material science, material development, fracture behavior of metals in high-pressure hydrogen;

**CIRI/Material Mechanics Lab** -- mechanical characterization of materials and failure analysis.

### 3. Management

H2FIRST will conduct its activities as a single operating organization co-led by SNL and NREL in consultation with the DOE/EERE Fuel Cell Technologies Office (FCTO). The following sections describe the organizational construct and the roles and responsibilities for partners.

#### 3.1 Organization

The collective leadership provided by SNL and NREL is called the Partnership Leadership Team (PLT). H2FIRST administration and organization is designed to be lightweight and flat, shifting research responsibilities to the stakeholders at the Project Team level while providing partnership management and coordination in connection with a Stakeholder Review Board (SRB), shown in Figure 4. The SRB is comprised of industry, university, and national laboratory partners along with representatives from coordinating, standards, and trade organizations connected with hydrogen infrastructure technologies. Project Teams are subsets of stakeholders and additional partners aligned around specific hydrogen infrastructure research challenges that evolve out of the SRB. As needs of the critical stakeholders evolve, Project Team activities may also evolve into longer-term core components of H2FIRST through standard contract mechanisms.

Partnership management will focus on partner recruiting, launching new collaborative projects, and ongoing coordination between H2FIRST, SRB, and Project Team activities. This type of partnership management will support developing collaborations and effective projects synchronized with the overall objectives of H2FIRST.

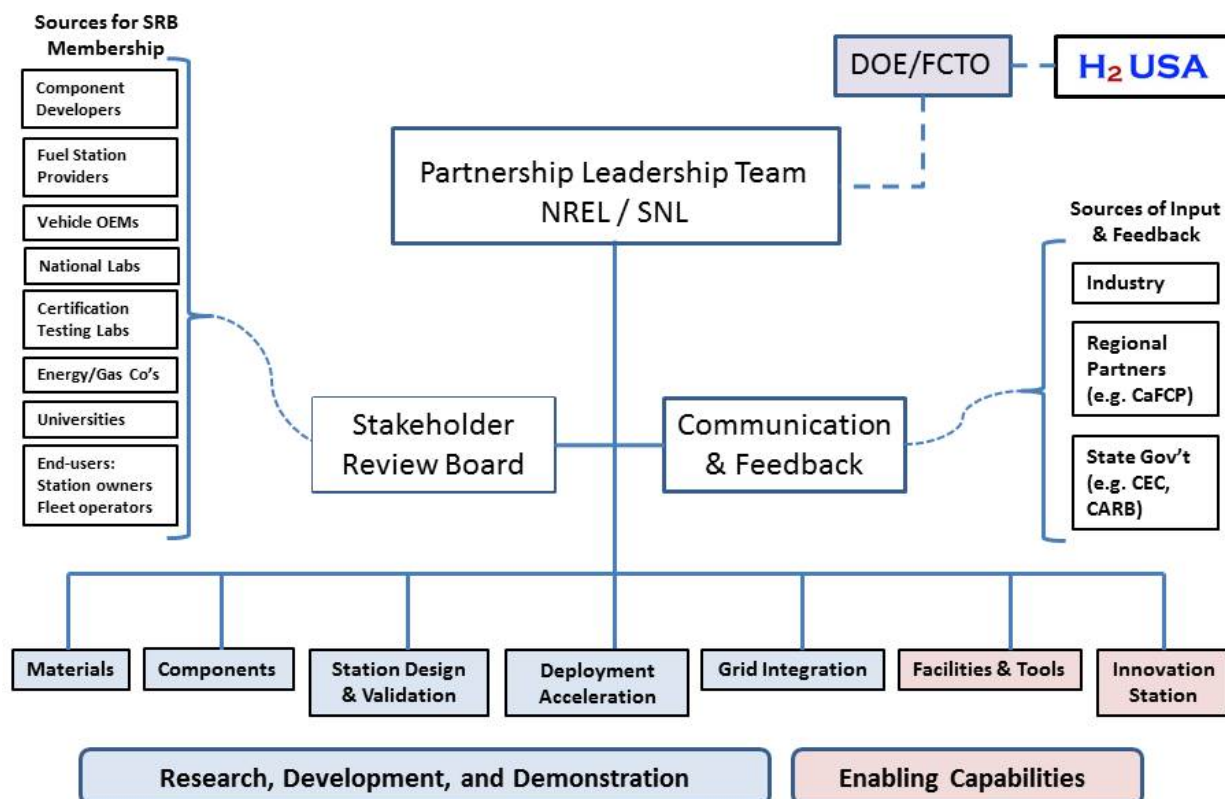


Figure 4: H2FIRST administration and organization are designed to be lightweight and flat, shifting research responsibilities to the stakeholders at the Project Team level while providing partnership management and coordination in connection with a Stakeholder Review Board (SRB). The DOE FCTO plays a special role as steward of national laboratory facilities. The Project Teams reflected in this structure are notional, reflecting the scope of work described in this whitepaper.

### 3.2 Roles & Responsibilities

**DOE/EERE FCTO** -- The DOE/EERE Fuel Cell Technologies Office (FCTO) provides strategic Program direction to H2FIRST and manages the DOE-funded H2FIRST projects. Roles and responsibilities of FCTO include:

- Provide strategic oversight and direction in alignment with DOE, EERE, and FCTO goals.
- Facilitate communication between H2FIRST and H2USA activities and help maintain respective mission boundaries; identify potential high-impact areas for H2FIRST to participate and contribute to H2USA.
- Coordination with State and Regional Agencies on H2FIRST scope and funding to enhance the value of strategic investments.
- Provide an Office Point of Contact to coordinate activities within FCTO.
- Manage DOE-funded H2FIRST activities as a part of the FCTO portfolio; Review milestones, project status, go/no-go decision points and criteria, and impact (qualitative and quantitative); Approve Annual Operating Plans with the Laboratories.
- Participate on the Stakeholder Review Board as an observer. Collect stakeholder feedback on H2FIRST priorities and investments.
- As stewards of the National Laboratories and their capabilities, provide feedback on proposed use of federal facilities in meeting H2FIRST objectives.

- Convene coordination meetings with other National Laboratories.
- Assist with implementation of Work for Others and CRADAs between National Laboratories and external partners.

***NREL and SNL*** -- NREL and Sandia will co-lead H2FIRST. Both Labs will identify a Partnership Director that is responsible for the administration and coordination. Roles and responsibilities of NREL and SNL include:

- Participate in the Partnership Leadership Team
- Serve as primary point of contact to the FCTO and their Office Point of Contact
  - Report on progress, milestones, technology status, lessons learned, impact and barriers to the FCTO
  - Provide objective evaluation of issues raised by stakeholders.
  - Negotiate the project Annual Operating Plans (AOPs) for the H2FIRST activities.
  - Deliver reports to the FCTO including Annual Merit Review materials, Quarterly Reports, Annual Reports.
  - Provide regular H2FIRST updates to the US DRIVE Tech Teams, specifically the HDTT and CSTT.
  - Provide reports and briefings to the Hydrogen Technical Advisory Committee (HTAC) and similar review bodies.
- Coordinate and perform administration of the Stakeholder Review Board
  - Establish terms and expectations for SRB participation.
  - Organize quarterly Stakeholder Review Board Meetings including two face-to-face and two interim web meetings.
  - Present annual report on H2FIRST accomplishments and plans.
  - Respond to recommendations from the Stakeholder Review Board.
- Integrate new Participants based on recommendations from Stakeholder Review Board. Involve FCTO in the approval process.
- Represent H2FIRST within H2USA working group and regional partnerships
- Perform as an interface to International efforts.
- Perform general H2FIRST administration including budgeting and project management.
- Manage external communications in partnership with FCTO about H2FIRST activities.
- Coordinate, develop and execute plans for critical capabilities that are necessary for the success of H2FIRST.
- In coordination with FCTO, engage additional National Laboratories that can provide technical expertise or facilities in support of H2FIRST and DOE goals for hydrogen infrastructure development.

***Stakeholder Review Board*** -- A Stakeholder Review Board will be assembled with representatives from a number of critical entities including, small, medium, and large business and state and local governments. Members of the SRB are expected to invest significant resources in H2FIRST. Roles and responsibilities of the SRB include:

- Help set directions and priorities for shared resources that align with the H2FIRST mission and serve National goals.
- Review H2FIRST progress and plans quarterly (two face-to-face and two interim Web meetings/teleconferences).
- Nominate a Chairperson from the private sector.

- Provide annual feedback for H2FIRST Leadership and DOE in written form.
- Each member provides a brief annual report that outlines how the represented entity is benefiting from the partnership.
- Catalyze, propose and assemble H2FIRST Project Teams around topics of interest.
- Propose strategic new members to the Partnership Leadership Team.
  - Membership can be proposed via SRB or Partnership Leadership Team sponsored nomination.

***Project Teams & Assignments*** -- Project Teams consist of collections of stakeholders that are uniquely aligned around a specific hydrogen infrastructure research challenge. The Project Teams form the core of H2FIRST where the scope and planning activities are performed. The Project Teams are formed on an as-needed basis from the Stakeholder Review Board and may consist of any number of the Stakeholder Review Board Members plus any critical partners that are necessary for the success of a specific Project Team. Each Project Team is led by a Member. Project Teams will have specific objectives and timeframes and will be subject to renewal or disbanded upon expiration via review by SRB. Roles and responsibilities include:

- Responsible for scoping, planning, and executing research.
- Developing and implementing contractual mechanisms between partners including CRADAs, WFOs, or other agreements.
- Provide the interface to partner Labs, academia, and other national and international research organizations
- Develop and implement management plans for Intellectual Property (IP).
- Provide reports on Project Team progress and plans to Stakeholder Review Board.
- Coordinate external funding.

### ***3.3 Partnership Metrics***

The effectiveness of the H2FIRST partnership will be measured by the creation of intellectual property (publications, patents, and licenses), infrastructure technology improvements, new businesses (spin-offs), new collaborations, satisfaction with H2FIRST activities as reported annually by Members, and achievement of the National goals.

### ***3.4 Evolution of the H2FIRST Partnership***

The Project Teams will provide a forum to allow the activities within H2FIRST to evolve based on the emerging needs of the critical partners and stakeholders. Project Team activities may evolve into longer-term core components of H2FIRST as sustained needs are identified. Examples of Project Team evolution may include:

- Small Business Support, Technology Transfer, Commercialization assistance
- Incubation Support/Process
- User-facility support
- Fuel retailer support (education, network, see ideas in deployment acceleration section)
- Industrial Fellows program

## **4. Research and Engineering Development**

Prior research, field data, and public meetings indicate that there are engineering and science challenges that inhibit the development of reliable, low-cost, high-performance fueling infrastructure systems. Success achieved thus far has been through the use of standard industrial



equipment and systems modified for the hydrogen fueling application. It is now time to develop hydrogen fueling-specific components and systems that optimize the unique design requirements for a variety of station sizes, value propositions, and market needs.

H2FIRST will evaluate new materials, emerging component technology, and novel system architectures in reconfigurable hydrogen fueling test loops. Performance and reliability issues will be addressed using a science-based approach with the intent of predicting aging behavior and lifecycle costs, utilizing a national network of tools, research capabilities, and testing.

#### **4.1 Station Optimization and Innovation**

The system optimization activity is focused on innovation and design of fueling stations that will meet the future needs of the consumer market while driving the cost to be competitive with today's liquid hydrocarbon transportation system. The unique test and evaluation facilities at the National Laboratories provide a national resource to test new concepts, validate models, and improve the confidence of investors and consumers. The optimization activity integrates modeling, stakeholder input, and technical performance metrics/targets together to develop optimal station designs. Examples of key considerations known today are: footprint, complexity, installation costs, availability, and cost per hydrogen kilogram. Optimized designs will also include the application and validation of modeling results with integrated, retail-like hardware testing.

##### **Goals**

The goals for the system optimization activity are to:

- Identify, optimize, and validate innovative system architectures to meet the commercialization goals for the 2017--2020 time period.
- Improve station siting and footprints.
- Provide reference station designs which represent the near-term cost and performance requirements for hydrogen fueling and help communication for policy, investment, and regulatory hydrogen infrastructure stakeholders (partnering with H2USA). Compare reference station parameters with scenario modeling (*e.g.* SERA and Street models) parameters to verify reference designs with the industry rollout scenario stations.
- Assess the sensitivity of hydrogen cost to station requirements.
- Provide input on hydrogen station requirements through a station design matrix that suggests direction, targets, and benchmarks for H2FIRST research, development, and demonstrations.
- Provide a publicly available station design methodology that facilitates market entry by small business and entrepreneurs. Improve and validate system design and performance analysis models.
- Provide data for the improvement and validation of techno-economic analysis models.

##### **4.1.1 Reference system design, status, and requirements**

Many barriers identified in the DOE FCTO Multi-Year Research, Development, and Demonstration (MYRDD) report relate to the challenges with hydrogen fueling infrastructure. Clear, concise station requirements are challenging because of the many options and influencing factors. Benchmarks and targets are necessary to track status, progress, and needs. Existing references are outdated--the most recent version was generated in 2006 and the stations listed in

that reference are not commonly used to describe a hydrogen fueling stations. This task supports determination and continuous updating of hydrogen station research directions and goals.

H2FIRST will develop reference station designs to provide greater fidelity in our understanding of the barriers inhibiting the realization of a hydrogen fueling infrastructure and provide quantitative station and station network requirements, cost targets, and performance/availability/reliability metrics.

#### **4.1.2 Develop and demonstrate optimized fueling station concepts**

The H2FIRST partners will design, optimize, and demonstrate advanced fueling station concepts. Optimization will occur through a comprehensive examination of the dynamic fueling process, using validated analysis tools. Optimizations may include component reductions and cost, energy efficiency, and performance improvements. A compression/storage/delivery+vehicle fueling model will be validated using the research dispenser (Task 4.2.2) and the station qualification hardware (Task 4.2.1). Validation may occur at the brass-board test facilities or at a demonstration “Innovation Station”.

#### **4.1.3 Station siting and footprint**

Reducing station size and footprint are important elements of an optimized design in Task 4.1.2. Footprint can be reduced through physical hardware configuration changes or by revising setbacks required by building and fire codes. H2FIRST partners will work with safety researchers and codes and standards developers to understand risk and develop hazard mitigation strategies that provide appropriate levels of protection for stations and the public.

### **4.2 Cost, Reliability, and Performance Engineering**

The current cost and reliability of the materials and equipment needed to handle high-pressure hydrogen from production through dispensing can benefit from improvements to ensure a widespread, commercially-viable hydrogen infrastructure. The activities that support this objective include characterization of component reliability and failure modes under well-controlled operating conditions and identification of opportunities for improving design and/or material usage. H2FIRST integrates high-pressure hydrogen materials science and high-pressure hydrogen component reliability testing expertise for failure analysis and reliability improvement campaigns. Innovative component technologies, subsystems, and protocols will be evaluated in-situ with performance, reliability, and safety assessments used to guide further development towards commercially viable products.

#### **4.2.1 Fuel station performance validation and qualification**

Hydrogen fueling is the interaction of two high-pressure hydrogen systems and a user. Hydrogen fueling also involves the business-to-consumer (B2C) transaction of vehicle motor fuel. This transaction often requires state regulatory inspection and verification. Motor vehicle fueling transactions are commonly monitored for *quality* and *quantity*. Hydrogen fueling stations also require compliance to a specific fueling protocol which ensures safety and prevents harm to the vehicle storage system; a *performance* requirement. Finally, much of the early infrastructure will be subsidized by state and federal government entities. These contracts are awarded based on the ability of the contractor to fill a minimum number of vehicles; a *capacity* requirement. Therefore hydrogen fueling systems have four general technical requirements in the areas of: *quality*, *quantity*, *performance* and *capacity*.



No test method exists for measuring capacity of a station. Secondly, the test method for performance, CSA HGV 4.3, is not yet validated. (The challenges of ensuring fuel quality are addressed in Task 4.2.5). U.S. DOE-supported activities are already underway regarding fuel quantity measurement (*i.e.* metering RD&D through RFP solicitations).

New test methods and validation experiments are needed to address performance and capacity. The performance activity will validate the relevant test methods of CSA HGV 4.3. This test will require a dispenser capable of SAE J2601 T40 compliance as well as performance of out-of-compliance fills (over/under pressure, over/under temperature). The “research dispenser”, described in Task 4.2.2, would meet this need. This performance testing also requires a set of instrumented and environmentally controlled vehicle fuel systems (of varying sizes to cover all three ranges described in the SAE J2601 document). This set of vehicle fuel systems combined with the research dispenser will also facilitate the development and validation of a capacity test method. This capacity test method is tentatively planned to reside in the CSA HGV 4.9 standard, however this standard is not yet published.

A successful accomplishment of this task results in validated test methods and hardware for capacity and performance:

- a validated station capacity test method;
- a validated station performance test method;
- validation of a breadboard fueling system, including research dispenser; and
- design, construction, and demonstration of instrumented vehicle fuel systems.

#### **4.2.2 Fuel dispensing controls and the vehicle interface**

The dispenser is a complex device which must accurately control the mass flow rate, temperature, and pressure increase rate for the fuel as it enters the vehicle. The dispenser must perform both communications and non-communications fueling. Furthermore, it must safely negotiate and appropriately respond to upset conditions, for instance, determining if a loss of communication should result in an aborted fill.

Published literature regarding dispenser system and component design is sparse, and no such dispenser exists within the public research portfolio. An open-architecture research dispenser is needed, capable of fueling within a pressure envelope up to 875 bar and delivering gas temperatures from -70°C to 140°C. These capabilities will ensure that the research dispenser will not only accurately provide fueling using the current protocol, but will be capable of investigating a wide range of fueling possibilities and protocols not yet proposed. The dispenser will function as a critical part of the research fueling station enabling such activities as fuel station qualification test method development.

Successful completion of this activity results in industry innovation efforts to advance the state of dispenser technology, thus providing a better user experience (faster filling, better user interface, and lower costs).

Outcomes envisioned:

- A dispensing system designed, constructed and commissioned to enable investigations of fueling capacity and performance.
  - A bill of materials with “off the shelf” prices for use by public and private investors and regional sponsors for planning purposes.
  - Validated models of the tank and dispenser fluid dynamics and heat transfer processes, including cryo-compression and high-pressure evaporators.
  - A publicly-owned training tool with open-source control software and design documentation.
- We will also evaluate simple, no-cost options to improve the current fueling approach. These could include replacing system integrity checks that add time to fill and protocol complexity with smart algorithms based on pressure decay or instantaneous target pressure. We will identify the engineering tradeoffs for various fueling protocols and identify optimized fueling methods that support the DOE requirements of \$0.70 gge CSD, non-communication, no pre-cooling, 7 kg dispensing (500 psi to 10000 psi) in five minutes.

#### **4.2.3 Pneumatic gas cycle testing type IV composite overwrapped pressure vessels**

Gas cycling effects on vehicle pressure system lifetime are a key design consideration and thus a cost driver for the overall FCEV – investigation of the impact of current vehicle tank design upon costs associated with fueling protocols (precooling) and lifetime sensitivity from station performance (fuel quality, pressure/temperature system controls, *etc.*) is needed. Several foundational activities may inform system design decisions:

- Perform pneumatic cycle testing of type IV composite overwrapped pressure vessels (COPV) to validate the temperature and pressure excursion-induced failure modes imposed by fuel dispensing at the materials level (not the system failure mode such as leak before break or damage tolerance).
- Characterize and demonstrate the blister fracture phenomena using full scale gas cycle testing, laboratory scale vessel samples, and material coupon samples (integrated with Task 4.2.9). Identify the impact of cost reduction trade-offs and provide critical data to the system cost reduction effort.

#### **4.2.4 Fill cycling**

We will investigate the impacts and solutions for back-to-back fueling dynamics in retail fueling scenarios.

- Benchmark reliability and performance issues associated with back-to-back fueling (*e.g.* nozzles frozen onto receptacles and longer fueling times) and model calibration.
- Benchmark frequent-fill challenges not yet seen in field deployments.
- Test and implement solutions to improve station back-to-back performance.

#### **4.2.5 Fuel quality**

Fuel cell electric vehicles have stringent requirements for hydrogen purity; specific requirements have been defined in SAE 2719 and ISO 14687. Failure to meet compliance has already resulted in damage to the fuel cell. The quality of dispensed hydrogen may be degraded from that of the produced hydrogen because of contamination introduced in transport, storage, compression, and other handling processes. Advances in sensor technology and portable detectors offer promise for the on-site, low-cost, real-time verification of fuel quality.

The current verification method for fuel quality is described as follows:

- Periodic, expensive sampling with remote laboratory analysis by gas chromatography (GC) for verification of compliance to regulatory requirements - being validated by ASTM<sup>4</sup>.
- Performed by a state regulator.
- Issues include cost, time delays, discreet points, and trained personnel for operation.

An in-line, on-site method for fuel quality is described as follows:

- Provide on-site, real-time analysis for target analytes and final verification of fuel quality just prior to dispensing.
- Sensor technology/portable instruments have the potential as low-cost, automated, systems.
- Catch out-of-normal situations before fuel is dispensed into a vehicle.
- Provide opportunity for station operators to take timely corrective actions to catch out-of-normal situations before dispensing into the vehicle.
- Issues include lower capability for contaminant detection than the current laboratory method and may only indicate that a problem exists with fuel quality without providing corrective actions or indication of the underlying cause of contamination.

Possible activities to support in-line fuel quality analysis are:

- Identify on-site quality measurement requirements and key contaminants associated with specific station type with help from OEMs and gas suppliers.
- Review sensor and detector availability that are rated and can survive station environment.
- Test at least three methods, focusing on performance, reliability, durability, and costs leading to the identification of the most promising sensing/detecting technologies. Data may identify need for a RFP/SBIR to support domestic sensor/detector development specific for the hydrogen fuel quality market.
- Field testing of promising sensing/detecting technologies for target analytes identified as important based on station type.

#### **4.2.6 Retail fuel metering**

It is necessary to continue development for accurate measurement of hydrogen under fueling conditions. Development could include novel measurement approaches and metering hardware validation.

- Define processes and systems for the retail sale of hydrogen that meets NIST Handbook 44 ( $\pm 1.5\%$  acceptance tolerance and  $\pm 2.0\%$  for maintenance tolerance).
- Develop, test, and transfer technology for the next phase of metering equipment.
- Evaluate novel business solutions for “meter-less” hydrogen sales for the mature retail market – validate with fueling data from test facilities as well as data in HSDC.
- Develop performance improvements to provide high quality hydrogen in a safe fashion with a trustworthy and fair retail transaction.

#### **4.2.7 Compressor reliability**

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<sup>4</sup> ASTM D7649-10 Standard Test Method for Determination of Trace Carbon Dioxide, Argon, Nitrogen, Oxygen and Water in Hydrogen Fuel by Jet Pulse Injection and Gas Chromatography/Mass Spectrometer Analysis.

Compressors are a leading cause of unplanned maintenance for hydrogen infrastructure. Components with low reliability create investment risk for station operators. H2FIRST offers the accelerated test capability to evaluate both performance and durability of compression equipment and identify technology and market gaps to feed back into the development process.

Activity level work has already begun in this area at NREL which is uncovering failure modes for commercially available and commonly used compressors. Reliability improvement includes characterization via accelerated lab testing and root-cause failure investigation, materials development and component designs, fix implementation, and field validation. The process is repeated until reliability meets or exceeds the targets developed iteratively through Objective 1. H2FIRST will work with compressor manufacturers to improve materials selection and identify design modifications with the aim of developing, demonstrating and deploying novel improvements to existing compression technology.

Specific activities:

- Identify primary failure modes through accelerated testing.
- Perform detailed failure analysis, including materials characterization and improvement.
- Work with compressor manufacturers to iteratively improve reliability, including material science and system-level solutions. Develop, demonstrate, and deploy novel improvements to existing compression technology
- Investigate alternatives to mechanical compression or hybrid compression systems that are more reliable than current methods.

#### **4.2.8 Hose reliability**

Dispenser hoses, like compressors, exhibit reliability issues in the field. These hoses develop unacceptable leaks after as few as 100 uses. For a station filling 15 vehicles a day, this may be a weekly replacement. Replacing the hose is non-trivial and requires special training and skills to accomplish. Therefore an effort that targets hoses is critical. Activity level work has already begun in this area at NREL.

We seek to increase hose lifetime from ~100 fills (estimated baseline life) to 20000 fills (notional) and reduce life-cycle cost (*e.g.* unit cost could be higher, but reduces O&M costs) and assure safety:

- Identify primary failure modes through accelerated testing
- Apply comprehensive stress analysis (and fluid dynamics if appropriate) to determine critical conditions at failure points (stress, temperature, gradients, abrasion)
- Identify materials solution to mitigate failure and work with manufacturers to build prototypes for evaluation (using capabilities developed in Task 4.2.9).
- Explore design modification (beyond materials selection) to improve performance and manufacturing using simulation tools developed to evaluate failures
- Work with manufacturers to iteratively improve reliability

#### **4.2.9 Non-metals materials characterization and reliability**

Polymer materials are currently used in fuel cell vehicle systems and fuel delivery and dispensing systems, most prominently for tank liners, hoses, seals, O-rings, and bonding. Non-metals are distinguished from structural metals in that they provide functional properties such as

liners and seals that do not require structural performance in the same way as metals. Moreover, the effects of static (isothermal) hydrogen exposure do not appear to degrade the basic integrity of polymer materials (SAND2014-193819388904). Pressure cycling with highly soluble gases, on the other hand, appears to induce internal damage in some polymeric materials, especially elastomers. The evolution of internal, furthermore, is likely sensitive to temperature as many polymer materials have a relatively narrow range of temperatures where they maintain their functional properties.

From a recent industry information exchange (SAND2014-1938193810860) on *Polymer and Composite Materials Used in Hydrogen Service* and subsequent literature reviews (SAND2014-193819382512, SAND2014-193819388904) of hydrogen effects on polymer mechanical performance, two issues stand out for immediate attention: (i) the need to develop in-situ mechanical testing/characterization methods for polymeric materials that evaluate their performance during high-pressure hydrogen exposure, pressure cycling, and at extreme temperatures, and (ii) comprehensive understanding of the blister fracture phenomenon and its effects on aging and reliability. Other important considerations, in particular friction and wear, are described in SAND2014-193819388904.

Specific activities:

- Develop concepts for evaluating damage accumulation (*e.g.* blister fracture) in polymers subjected to pressure cycling.
- Evaluate whether other gases (such as helium) can be surrogates for damage characterization.
- Characterize mechanical performance of relevant polymer materials in high pressure gaseous hydrogen, and at extreme temperatures.
- Provide leadership for standards to qualify polymer materials for hydrogen.
- Extend chapters on polymer compatibility in the *Technical Reference for Hydrogen Compatibility of Materials* (SAND2014-193819387321) to include relevant materials properties/characteristics.

#### **4.2.10 Develop and characterize low-cost structural materials**

Austenitic stainless steels are acknowledged as high-performance materials for hydrogen containment components; however, these materials are alloyed with expensive elements such as nickel. Consequently, materials can constitute a significant fraction of the total cost for hydrogen containment systems fabricated from stainless steels. Candidate materials for replacing current high-performance stainless steels may include alternate stainless steels with lower nickel content and aluminum alloys. Among common structural metals, ferritic steels generally have the lowest cost, but these materials can exhibit pronounced effects of hydrogen embrittlement (as well as atmospheric corrosion). Comprehensive materials testing will be required to evaluate the suitability of alternate materials for components currently fabricated from high-nickel stainless steels, particularly since there may be no service experience with alternate materials in such components (*e.g.*, valve bodies and composite tank valve bosses).

The testing required to qualify materials as alternatives to high-nickel stainless steel must focus on measurement of design-relevant properties, *i.e.*, fatigue life. One approach to measuring fatigue life that can be explicitly applied in design was recently published in the CSA CHMC1 standard. Following this approach, the total fatigue life of representative structural metals for

hydrogen components is measured under expected service conditions, *e.g.*, hydrogen gas pressure and temperature. Since the high ductility and corrosion resistance of stainless steels will lead to their continued use in high-pressure hydrogen components, this activity will emphasize fatigue life testing of lower-cost stainless steels. Such lower-cost stainless steels may be commercially available materials that require more comprehensive characterization (*e.g.*, 304L stainless steel) or new stainless steel compositions. In either case, characterization of fatigue properties at sub-ambient temperature is a priority.

In this task, we will identify promising pathways for improving the hydrogen compatibility of high-strength materials. Once compelling candidate materials are selected and procured, the mechanical properties of the materials will be characterized in high-pressure hydrogen gas. Initial testing will focus on screening materials following standardized methods developed for hydrogen gas. Once a collection of materials is identified for additional characterization, further testing will emphasize measurement of material properties that can be directly applied in design.

Specific activities:

- Demonstrate performance of low-cost, commercially available austenitic stainless steels for service in high-pressure hydrogen environments; build strategic partnerships to develop high-strength alternatives to high-nickel austenitic stainless steel.
- Characterize the fatigue behavior of low-cost austenitic stainless steels in hydrogen environments (-40°C to 85°C) to achieve material cost reduction of 25% (relative to the benchmark of type 316L).
- Characterize the fatigue behavior of high-strength alternatives to type 316L austenitic stainless steel in hydrogen environments to achieve material cost reduction of 50% over the temperature space relative to FCEV.

#### 4.3 Deployment Acceleration

Past experience has shown that unanticipated issues can arise during all stages of hydrogen station implementation, from design through operation. Examples include the need for independent review of component and system designs, commissioning problems with specialized equipment, code/permitting and educational needs, and breakdowns or incidents during operation. Initial deployments are especially sensitive to this problem because of a lack of robust expertise in the industry, making it difficult to resolve issues in a timely manner.

H2FIRST provides a flexible, responsive set of technical experts and facilities that will solve urgent challenges and the unpredicted needs that come up for hydrogen stations. A lessons-learned database of challenges with a point of contact and open-source user interface for end-users to quickly fix an issue and also submit issues would be helpful (goes beyond equipment—could include finance, policy, codes and standards).

#### 4.4 Renewable Pathways and Grid Integration

A long-term goal of the project is to enable the use of distributed renewable hydrogen production in a fuel distribution network.

*A need to stabilize the electric grid*--the supply of available renewable electricity on the national grid is increasing due to lower costs and legislative mandates. For example, in 2011 California passed a bill that requires 33% of electricity generation to come from renewable resources by

2020. Increased penetration of wind and solar-generated electricity demands more energy time-shift capabilities (sometimes referred to as arbitrage) and more of the so-called “ancillary services.” Among others, these include regulation (generation/load balancing), dynamic scheduling of generation and loads, and transmission stability and damping.

*A technology that overlaps both needs*--electrolysis of water to produce hydrogen, becoming known as “power to gas,” is a mature technology demonstrated at DERTF. When the electricity used for electrolysis comes from renewable sources, the hydrogen produced is considered zero-carbon or carbon-neutral. However, the cost of hydrogen from electrolysis is often greater than that produced by steam methane reforming, and while some technology improvements will be able to reduce the cost, it is still highly dependent on the cost of the supplied electricity. DOE estimated that the cost of electricity would need to be \$0.037/kWh to produce cost-competitive hydrogen at the dispenser (\$4.00/gge)<sup>5</sup>, which is currently less than the actual retail price of delivered electricity in any part of the United States<sup>6</sup>.

However, when an electrolyzer can provide a service to the electrical grid (called “grid-integrated electrolysis” here) the owner/operator can receive compensation in the form of revenue, reduced electrical rates, or both. This revenue can be used to offset electrolysis cost and has the potential to make hydrogen generation via electrolysis a true cost-competitive alternative.

There are several possible methods to deploy grid-integrated electrolysis for cost-effective hydrogen generation. In general, the most practical seem to be:

- Small-scale distributed electrolysis ( $\leq 1$  MW;  $\leq 400$  kg/day) located at the point of hydrogen use.
- Small- or medium-scale electrolysis located at strategic points on the electrical distribution grid.
- Medium- or large-scale electrolysis located at strategic points on the electrical transmission grid.
- Small to large-scale electrolysis located at the point of renewable generation

In all cases but the first, hydrogen transportation must also be factored into the cost at the dispenser unless co-location of hydrogen demand and grid need exists and hydrogen generation capacity matches demand. Traditional options for transporting hydrogen are by truck (liquid or gas) or by dedicated pipeline. There are also options that involve natural gas: 1) injecting into existing natural gas pipeline and extracting (via separation technology) at a different location, 2) injecting into natural gas pipeline and using on-site reformation to recover pure hydrogen, or 3) converting to methane at the point of generation, injecting into the pipeline, and then using on-site reformation to recover the hydrogen.

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<sup>5</sup> DOE’s Multi-Year Research, Development and Demonstration Plan for Production, 2012.

<sup>6</sup> US Energy Information Institute, Electric Power Monthly report for September, 2013.

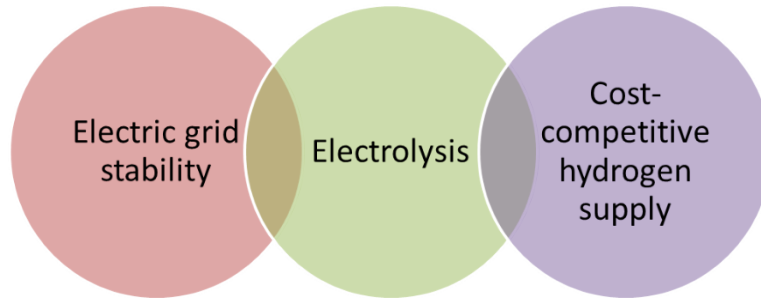


Figure 5: Hydrogen generation via electrolysis has the potential to meet two needs at once: electric grid stabilization and cost-competitive hydrogen production.

The obstacles to implementing cost-competitive hydrogen production via grid-integrated electrolysis can be classified by three categories: 1) it costs too much (economic), 2) it doesn't work (technical), and 3) it's not allowed (regulatory). In turn, there are three application areas where these obstacles are encountered -- grid integration, hydrogen production via electrolysis, hydrogen distribution. In this context, this section identifies and discusses three RD&D tasks needed to enable cost-competitive hydrogen production via grid-integrated electrolysis.

### Goals

- Demonstrate advanced renewable electrolysis systems suitable for deployment
- Demonstrate how hydrogen production can help stabilize the grid while enabling a higher penetration of renewables and providing a high-value transportation fuel.

#### 4.4.1 Evaluate options for grid-integrated electrolysis

Conduct economic, technical, and regulatory screening of the options for cost-competitive hydrogen production via grid-integrated electrolysis.

#### 4.4.2 Validate grid service capability of large-scale electrolyzer technology

Within the scope of H2FIRST, we will work with industrial partners (electrolyzer suppliers) to validate new, large scale electrolyzer technology for both efficiency improvements and grid interaction capability.

#### 4.4.3 Enable standards for injection of hydrogen into natural gas pipelines

The injection of hydrogen into existing natural gas pipelines is not typically allowed by either regulation or pipeline owner practice due to operating and safety concerns. However, the justification for these concerns is not clear and accurate technical evaluation of the effects of hydrogen injection must become better understood. This includes the material interactions (effect of increased hydrogen concentration on pipeline materials, characterization of existing pipelines), and the non-material effects (effect of hydrogen enriched gas on compressors, safety equipment, users, *etc.*).

High-purity separation technology is needed for extraction of hydrogen blended into natural gas pipelines for transportation. Currently available technology has cost and operational drawbacks that would make this option economically challenging even if hydrogen transport by natural gas pipeline becomes accepted.



- Provide the technical basis needed to support or revise current regulations and practices regarding injection of hydrogen into natural gas pipeline.
- Conduct engineering evaluation of pipeline materials exposed to hydrogen blends to quantify the effects of hydrogen and develop a technical basis for evaluating acceptable limits on hydrogen blended in the natural gas.
- Improve hydrogen separation technology.

## 5. Enabling Capabilities and Facilities

H2FIRST's unique capabilities are infrastructure and hardware evaluation facilities, material science and engineering tools and expertise, and certification. The core capabilities of hardware evaluation and material science are delivered through the CIRI at Sandia National Laboratories and the ESIF and DERTF at the National Renewable Energy Laboratory, while certification capabilities reside with external partners. Capabilities and facilities are described in the following sections.

### 5.1 Material science and engineering science capabilities

The Center for Infrastructure Research and Integration (CIRI) at Sandia National Laboratories maintains the equipment, experts, and partnerships required to understand materials and component behavior in relevant hydrogen environments. These enabling capabilities have demonstrated national impact in the following areas: 1) support of the 2015 worldwide deployment of fuel cell electric vehicles by providing the science basis for the published fuel system performance standards and regulations, *e.g.* SAE J2579 "Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles" and Global Technical Regulation, and 2) supported the market expansion of fuel cell forklifts from 1000 to greater than 5000 units by developing scientifically-sound performance-based design standards for low-cost fuel systems for industrial trucks.

CIRI leverages the unique approach to high-pressure hydrogen systems based on Sandia's historical role for the DOE National Nuclear Security Administration (NNSA), namely, material science informing the design and stockpile support of Gas Transfer Systems. Sandia is capable of conducting research to transfer safe, accurate, and trustworthy knowledge and technology innovations of high-pressure hydrogen systems to support domestic-based certification test companies, suppliers, integrators, and fueling infrastructure providers. Sandia is confident in this role as Sandia is already responsible for the design and delivery of hydrogen isotope systems that are absolutely safe, secure and reliable.

DOE has invested in excess of \$45M in unique capital equipment that is used collaboratively with industry and academia to understand hydrogen interactions and material mechanics in static-load and fatigue conditions at hydrogen pressures in excess of 1000 bar and temperatures ranging from -70 to 100°C. Existing facilities and laboratories included in the current CIRI portfolio are:

- Hydrogen Effects in Materials Laboratory -- characterization of materials performance in hydrogen at pressure and temperature,
- High-Pressure Engineering Laboratory -- high-pressure system engineering and testing capable of hydraulic and pneumatic testing of components at service conditions,

- Material Mechanics Laboratory -- evaluation and testing of structural materials performance and failure mechanisms,
  - Welding Laboratory -- development of advanced welding methods for high-pressure systems.
- These capabilities will be improved as required by evolving R&D needs. Some needed improvements have already been identified such as the extension of the fatigue testing capability to -70 °C.

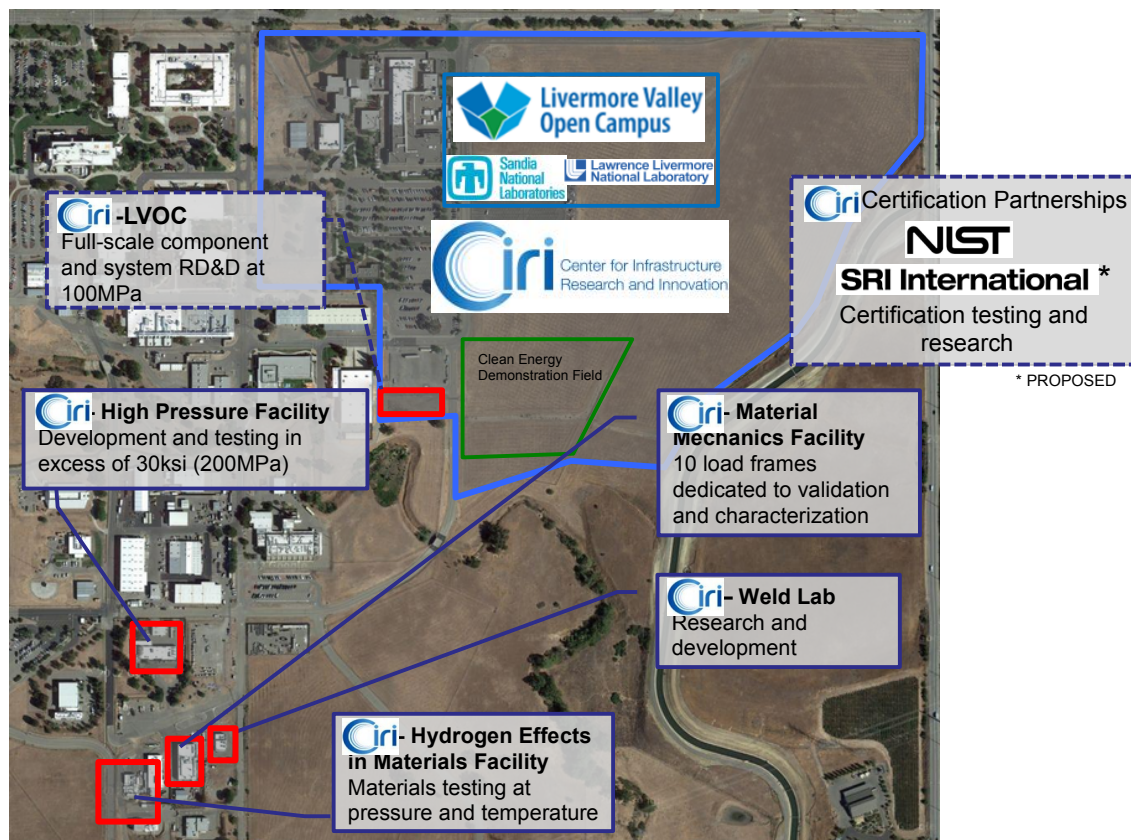


Figure 6: Ciri Facilities – existing (solid border) and proposed (dashed border)

## 5.2 Infrastructure and hardware evaluation facilities

The activities that enable the improvement of hydrogen fueling infrastructure require real-world exposure without compromising availability of existing retail stations. Research activities will also require variations to or additional measurement and test equipment that would be impractical at retail stations. Research facilities will similarly serve the role of education and outreach, also preventing a compromise with availability of retail stations.

### NREL -- Energy Systems Integration Facility

NREL's multistory Energy Systems Integration Facility (ESIF) provides laboratory and office space for approximately 200 NREL researchers and support staff. The 182,500-ft<sup>2</sup> building houses research to overcome challenges related to the interconnection of distributed energy systems and the integration of renewable energy technologies into the electricity grid. ESIF is the latest addition to the DOE's national network of user facilities and includes 15 laboratories with unique capabilities where organizations can partner with NREL to research and collaborate on energy system integration projects.

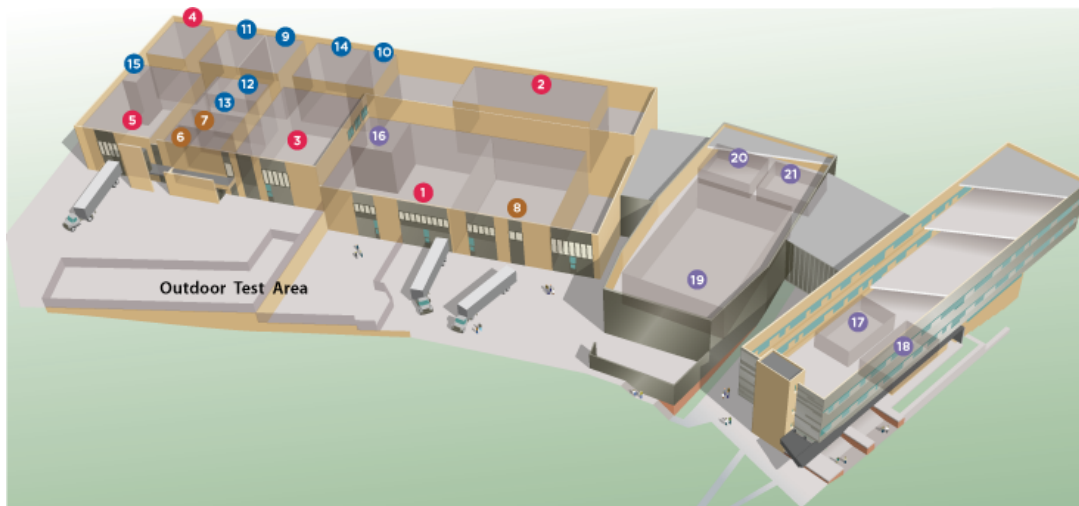


Figure 7: NREL's Energy Systems Integration Facility

Each of ESIF's electrical and fuel systems laboratories are designed and equipped for research, development, and demonstration projects involving key electrical and transportation fuel components of emerging integrated future energy systems. These laboratories each offer potential for single large experiments designed to apply several components in a closed loop or connected to external hardware or simulations.

The highly flexible design of these laboratories allows them to be safely divided into multiple test stand locations to enable work on independent equipment development and experimentation by multiple users. This design also allows maintenance to occur in one or more sections of a lab while work continues elsewhere, ensuring maximum availability and function to the user community.

Research activities conducted in ESIF's fuel systems laboratories support the DOE Core Competency in Systems Engineering and Integration by allowing users to develop and design new fuel system controls, models and feedback loops that communicate with electrical and thermal components of emerging future energy systems to enable interoperability and overall system performance. The ESIF contains the following laboratories relevant to the H2FIRST mission:

- Hydrogen Generation, Compression, Storage and Dispensing
  - 12-kg/day electrolyzer generation
  - 6000-psi compression (diaphragm)
  - 80-kg 6000-psi storage
  - Dual 13000-psi compression
  - 35-kg 13000-psi storage
  - Type A -40°C chilling
  - 700-bar (nom) dispensing
  - Research Electrical Distribution Bus (REDB) capability for grid integration

The High-Pressure Test Lab provides space where high-pressure hydrogen components can be safely tested. The laboratory is co-located with energy storage activities such as ultra- capacitors, super conducting magnetic flywheel and mechanical energy storage systems for an integrated approach to energy storage system development and demonstration. The walls of the Energy Systems High Pressure Test Laboratory are built from concrete, capable of sustaining an overpressure condition or in the case of a component failure during test, and can act as secondary containment. Remote data and remote cameras are used for test observation, providing the added safety mechanisms needed. A critical understanding of component failure modes is essential in developing protocols for accelerated life testing to accurately scale to real world conditions is essential for developing regulations, codes and standards required for safe operation.

The Energy Systems Sensor Laboratory is designed to support research, development, testing and evaluation of advanced hydrogen sensor technologies to support the needs of the emerging hydrogen infrastructure. Information gained from the sensor testing can aid sensor technology development, selection and deployment, and development of codes and standards. The laboratory also provides support to end-users, including assessment of technologies to be used in applications and deployment.

The Energy Systems Integration Laboratory provides a flexible, renewable-ready platform for research, development, and testing of state-of-the-art hydrogen-based and other energy storage systems. The main focus of the laboratory is assessment of the technical readiness, performance characterization, and research to help industry move these systems towards optimal renewable-based production and efficient utilization of hydrogen. Research conducted in the Energy Systems Integration Laboratory will advance engineering knowledge and market deployment of hydrogen technologies to support a growing need for versatile distributed electricity generation, applications in microgrids, energy storage for renewables integration, and home and station-based hydrogen vehicle fueling.

The Materials Characterization lab supports the physical and photo-electrochemical characterization of novel materials. In this laboratory, a suite of analytical instrumentation and techniques enables the characterization of unknown material samples by identifying and quantifying present molecular species. This leads to the ability to de-convolute decomposition routes and elucidate reaction mechanisms of materials through thermal and evolved gas analysis. This aids in the synthesis of next generation materials that are tailored to optimize stability and performance.

The National Fuel Cell Technology Evaluation Center (NFCTEC) plays a crucial role in NREL's independent, third-party analysis of hydrogen fuel cell technologies in real-world operation. The NFCTEC is designed for secure management, storage, and processing of proprietary data from industry. Access to the off-network NFCTEC is limited to NREL's Technology Validation Team, which analyzes detailed data and reports on fuel cell technology status, progress, and technical challenges.

#### ***NREL – Distributed Energy Resources Test Facility***

NREL's Distributed Energy Resources Test Facility (DERTF) is a working laboratory for interconnection and systems integration testing. This state-of-the-art facility includes generation,



storage, and interconnection technologies as well as electric power system equipment capable of simulating a real-world electric system.

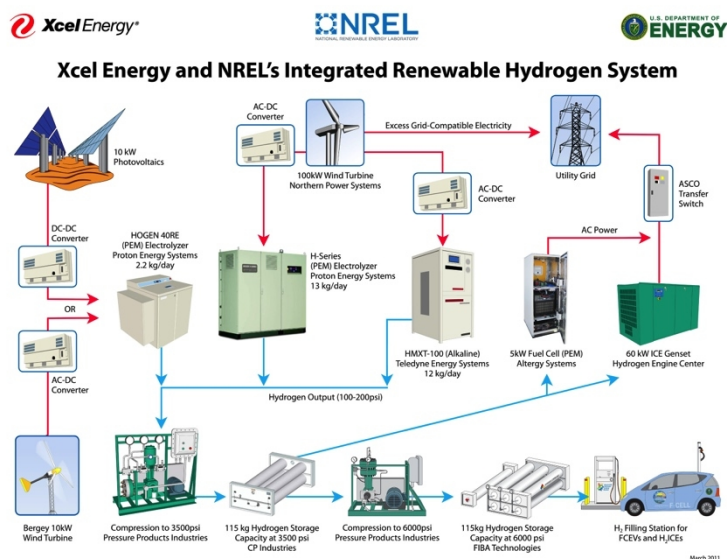


Figure 8: NREL/Xcel Energy Integrated Renewable Hydrogen System

### *SNL -- CIRI Full Scale Hydrogen Research Facility*

The CIRI Full Scale Hydrogen Research Facility (CIRI HyReF) provides a research platform for research and development of higher performance and lower cost hydrogen fueling systems and components. The facility features both accelerated high pressure hydrogen testing and hydrogen dispensing functions to meet system and component level research goals.

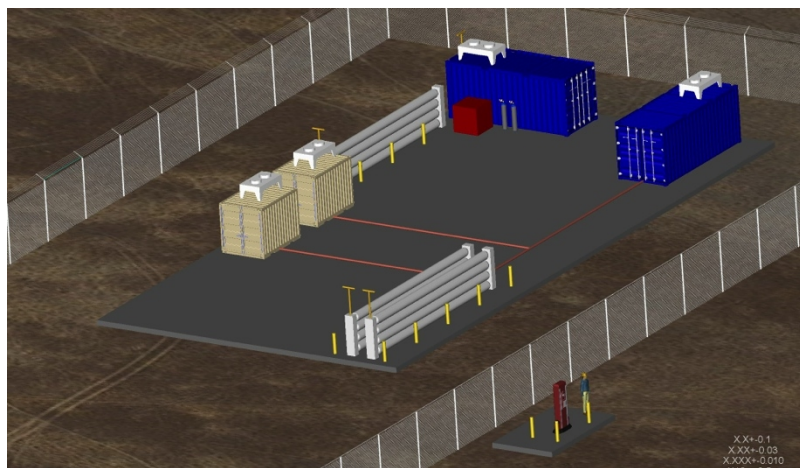


Figure 9: CIRI HyRef

Hydrogen fueling system engineering research and development is supported by a fully configurable layout. This allows for hardware evaluation of various fueling component

configurations, component technologies, fueling controls strategies, fueling protocols and fueling system performance evaluation tools.

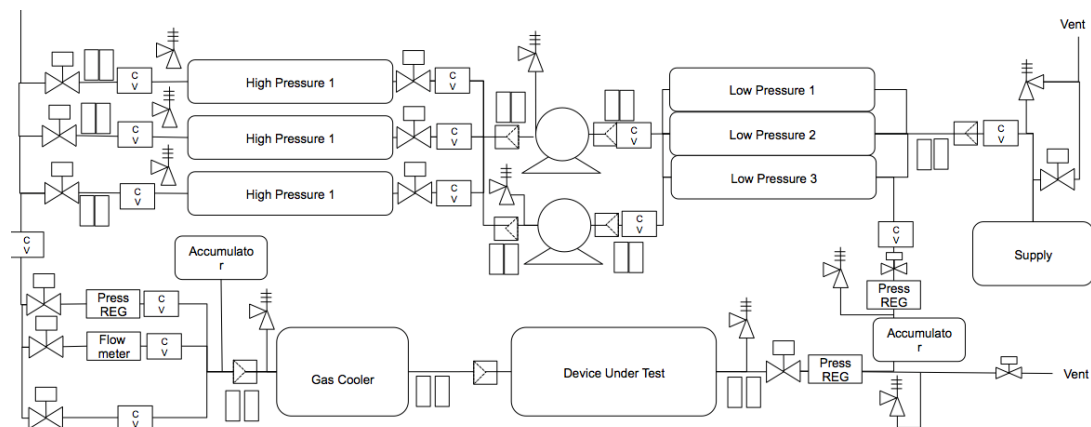


Figure 10: CIRI HyRef configurable layout

<b>High Pressure Storage Capacity</b>	<b>25 kg<sup>+</sup></b>
<b>High Pressure Storage Pressure</b>	<b>100 MPa</b>
<b>Low Pressure Storage Capacity</b>	<b>40 kg</b>
<b>Low Pressure Storage Pressure</b>	<b>35 MPa</b>
<b>Minimum High Pressure Gas Temperature</b>	<b>-70°C</b>
<b>Minimum Environmental Temperature</b>	<b>-70°C</b>
<b>Maximum High Pressure Gas Temperature</b>	<b>140°C</b>
<b>Maximum Environmental Temperature</b>	<b>140°C</b>
<b>Data Accuracy Target</b>	<b>&lt;1% Error</b>
<b>Hydrogen Source</b>	<b>On-site Electrolysis*</b>

### Certification Partnerships

There is no domestic certification test facility capable of testing/certifying tanks. H2FIRST would identify potential partner facilities, specify necessary capabilities, and provide insight into the challenges facing commercial test facilities presented by the requirements in hydrogen component standards.

For example, SRI's Corral Hallow Test Site has conducted several large-scale validation experiments in collaboration with Sandia's Safety, Codes and Standards projects. Many of the code improvements incorporated in NFPA 2 are a result of model validation experiments, such as flame impingement on walls, tunnel releases and most recently indoor hydrogen releases, conducted at the Corral Hallow. The Corral Hallow Test Site is capable of certification tests such as engulfing bonfires, burst tests, and high strain-rate impact tests of full components. SRI is a capable and willing technology partner for developing domestic certification testing of high-pressure hydrogen components and systems.

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